OPTIMISING VORTEX COOLING TIME FOR INDUSTRIAL LOCKSTITCH SEWING MACHINES

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ABSTRACT

Forced air or vortex cooling is the most common method for cooling sewing needlesin heavy industrial sewing machines, for example, in the automobile industry. The vortex tube separates compressed air into hot and cold streams, with the cold stream being continuously pointed at the sewing needle, decreasing the needle temperature. In this research, the impact of air cooling is determined for sewing without cooling, sewing with continuous cooling and sewing with optimised cooling times. For the optimised cooling time, the cooling is performed only at the time of stoppage during the sewing process. The results show that the impact of continuous cooling and cooling before sewing stoppage aresimilar, thus it is unnecessary to maintain continuous cooling.The sewing process is performed using two polyester core-spun threads with classic denim fabric, and the tensile properties of the threads are compared at different speeds of sewing (from 1000 to 4700 r/min) at continuous cooling, the optimised cooling time and without cooling. The resultsshow a 30% decrease in the tenacity of the thread when sewing without cooling, followed by the continuous and optimised cooling time, which decreases the needle temperature by almost 100°C and the tenacity of the thread by just 14%. Cooling only during machine stoppage or deceleration can save 60-80% of the energy consumption.

KEYWORDS: Sewingneedle, Needle Temperature, Needle Heat Cooling

INTRODUCTION

Industrial sewing is one of the most common manufacturing operations, and its applications can be found in the manufacturing of garments, shoes, furniture and automobiles. Every day, millions of products ranging from shirts to automotive airbags are sewn. Hence, even small improvements may result in significant corporate benefits. Heavy industrial sewing, such as that used in the manufacture of automobile seat cushions, backs and airbags, requires not only high production but also high sewing quality (i.e. good appearance and long-lasting stitches). In recent years, in order to increase production, high-speed sewing has been extensively used.Currently, sewing speeds range from 10~100stitches/sec, and in heavy industrial sewing, typical sewing speeds range from 16~50stitches/sec [1].

Inserted thermocouple method is an efficient method for sewing needle temperature measurement [2], and it can be used to measure the needle temperature during the sewing process at different speeds of sewing. Depending on the sewing conditions, the maximum needle temperatures range from 100~300°C [1]. This high temperature weakens the thread, since thread tensile strength is a function of temperature [2], resulting in decreased production[3]. In addition, the final stitched thread has 30–40% less strength than the parent thread [4]. As a result of the improved understanding of the causes of sewing damage, many technical developments, such as improved needle design [6,7], fabric finishes [8,9], thread lubrication and needle coolers [9,10], have been implemented over the years.

Forced air cooling is considered to be the most efficient method for decreasing needle temperature. Compressed air of 600–1000kPa pressure is pointed at the needle through a vortex tube which separates cold air ranging in

temperature between -20°C and 10°C, depending on the pressure and efficiency of the vortex tube [5].In our research, we optimised the time of cooling to 10 sec, starting 5 sec before machine stoppage.

MATERIALS AND METHODS

For this research, sewing was performed for 30 sec with two common industrial polyester threads, and the needle temperature was measured using the inserted thermocouple method for the different speeds of sewing, ranging from 1000 to 4700r/min. Finally, the tensile properties, like the initial modulus, breaking elongation and the tenacity of the thread,were measured at the different speeds and cooling times. The conditions for all of the experimentswere kept constant at 26°C and 65%RH.The devices used for the experiments are listed below:

- Lockstitch machine (Brother Company, DD7100-905).

- Thermocouple by Omega (K type 5SC-TT-(K)-36-(36))for the inserted method.

- Thermocouple by Omega -wireless device and receiver (MWTC-D-K-868).

- Needles(Groz-Becker 100/16) R-type.

- Sewing thread properties are shown in Table 1.

- Fabric properties are shown in Table 2.

- Forced air cooling device (Properties shown in Table 3.).

Table 1: Properties of the Sewing Thread

Thread Type	Producer/ Product Name	Yarn Count(tex)	Twist (t/m)	Twist Direction (ply/Single)	Tenacity (cN/tex)	Elongation at Break (%)	Initial Modulus (N/tex)	Coefficient of Friction, μ (-)
PES–PES core spun	AMANN/ Saba C-35	40 × 2	534	Z/S	50	18	4.4	0.16
PES–PES core spun	AMANN/ Saba C-80	22.2 × 2	660	Z/S	45	21	3.26	0.14

Table 2: Properties of the Fabric

Fabric Type	Weave	Weight (g/m^2)	Ends/cm	Picks/cm	Thickness(mm)
100%cotton Denim	2/1 Twill	257	25	20	0.35

Table 3: Vortex Tube Efficiency

Company	Input Air Pressure (kPa)	Output Air Temperature (°C)
Festo	500	7

The sewing process was performed for 30secof continuous stitching on 2 layers of fabric withneedle cooling, without needle cooling and with the optimised cooling time. Each thread was observed 20 times at each of the different speeds of sewing. The stitch length was kept constant at 5stitches/cm, and the results are presented in the next section.

Needle Cooling Setup

Figure 1 shows the placement of the cooling tube near the sewing machine; the distance between the needle and the cold air tube is 4 cm.Below isa description of the points mentioned in the figure:

- **Point 1**- vortex tube

- **Point 2**-air inlet from compressor

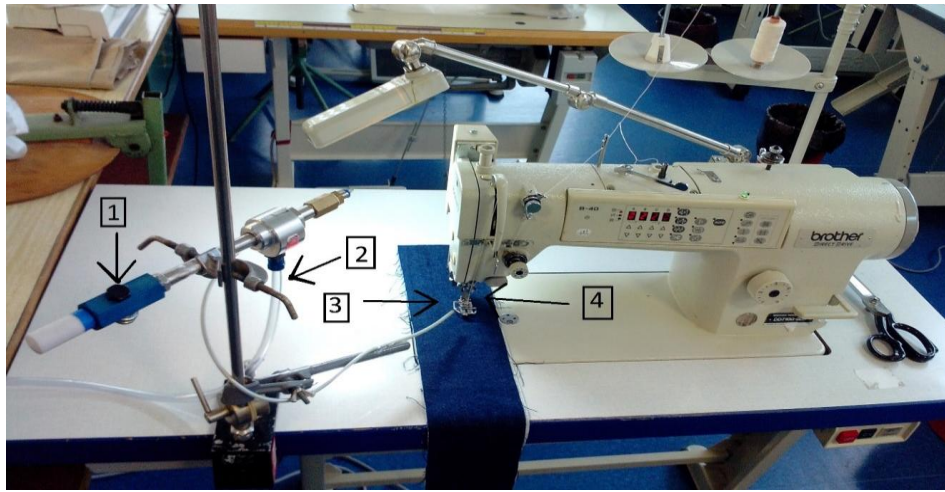- **Point 3**-cold air outlet

- **Point 4**- sewing needle

Figure 1: Sewing Machine with Needle Cooling Setup

Tensile Properties Measurement

After each 30 sec of the sewing cycle, the thread was cut from the needle guide point and a sufficient amount of seam thread was pulled out precisely by cutting the bobbin thread. Twenty observations were performed for each speed of the machine with cooling, without cooling and with the optimised cooling time, respectively.Tensile testing of the sewing thread was conducted on an Instron tensile tester as per ASTM standard D2256, with a gauge length of 250mm.

The change (%) in the tensile properties with respect to the parent thread was calculated by the following expression:

$$Change\ (\%) = \frac{Tn-T}{T} * 100 \qquad\qquad (1)$$

Where Tn is the tensile property of the thread pulled out from the seam, with n = 1, 2, and 3 corresponding to sewing without cooling, with cooling and with the optimized cooling time, respectively. T is the tensile property of the parent thread. A negative sign (–) indicates a loss in tensile property.

Cooling Time of the Needle

First, the sewing process was performed without cooling, and all of the observations of the needle temperature and the tensile properties of the final seam thread were recorded at the different speeds of sewing. Next, the sewing process was performed with continuous cooling, and the cooling of the needle was begun a few seconds before the beginning of the sewing process. Finally, the sewing process was performed with a partial cooling time of only 5 sec before and 5 sec after the stoppage of the sewing process. In total, 10sec of cold air was pumped manually at the sewing needle beginning at 25 sec of stitching and finishing 5 sec after the stoppage of the sewing. The reason for choosing this timing was mainly to protect the thread from damage at the time of the machine stoppage, where the contact time between the thread and the hot needle was much higher when compared to sewing at high speeds. The results and discussion are presented in the next section.

RESULTS AND DISCUSSIONS
Needle Temperature (Without Cooling) at Different Speeds of the Sewing Machine

Figures 2 and 3 show the needle temperature for both threads at the different speeds of sewing, without the air

cooling.The needle temperature is higher for the higher count thread, thread Saba C-35 shows a nearly 20°C higher temperature than the Saba C-80. This may be due to the higher contact area between the needle eye and the thread.
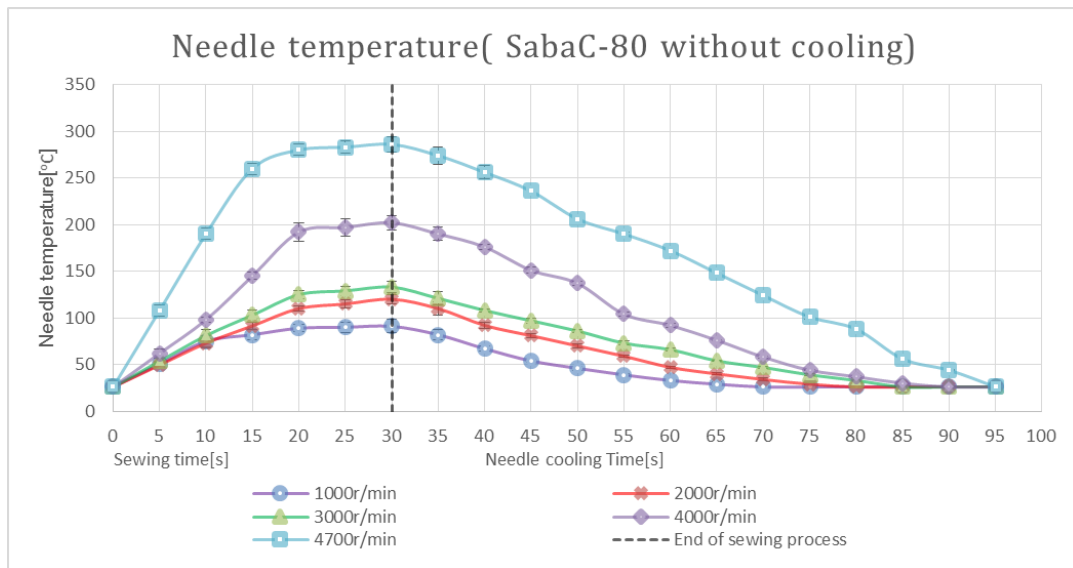

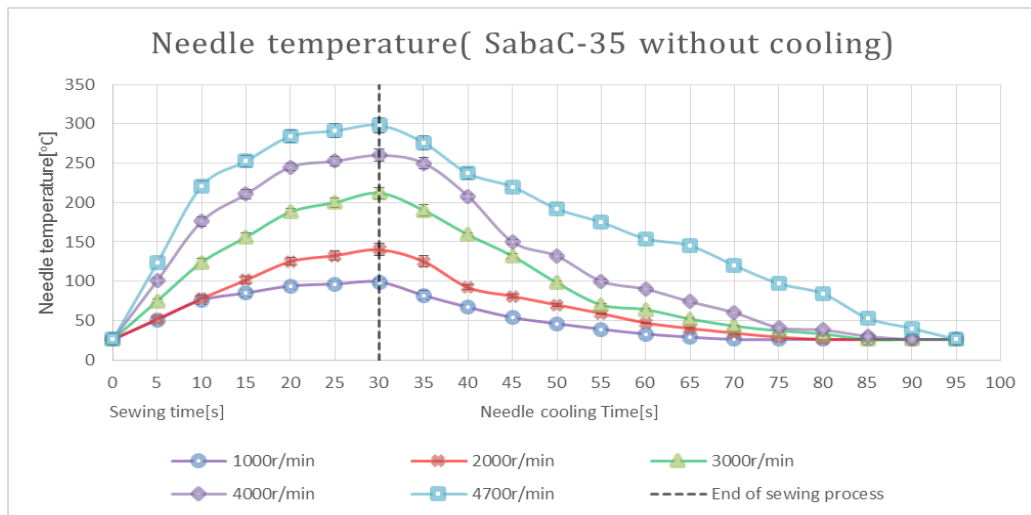**Figure 2: Needle Temperature (SabaC-80 without Cooling)**

Figure 3: Needle Temperature (SabaC-35 without Cooling)

Comparison of Needle Temperature with Optimised Cooling Time

The needle temperature at 1000 and 2000r/min was less than 150°C after 30sec of continuous sewing; therefore, 3000 to4700r/min was selected for the comparison of the needle temperature with cooling, without cooling andat the optimised cooling time.

Figures 4–9 show the comparison of the needle temperatures for the Saba C-80 thread at different speeds of sewing for all 3 cooling times. The legends for Figures 4-9 are described in Table 4.

Table 4: Description of Legends Used in Figures 4-9

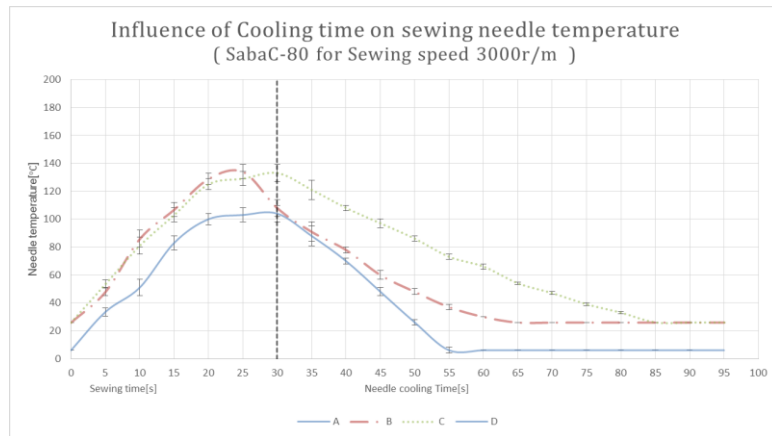| Legends	Description
A	Needle temperature with continuous cooling
B	Needle temperature with partial cooling(cooling starts at 25sec and ends at 35sec)
C	Needle temperature without cooling
D	Dotted line at 30secindicates the end of sewing process

Figure 4: Influence of Cooling Time on Sewing Needle Temperature (SabaC-80) at 3000r/min of Machine

Figure 4 shows a nearly 30°C difference between sewing with air cooling and sewing without cooling. The optimised cooling time of 10 sec, beginning at 25 sec of the sewing process, causes the needle temperature to decrease dramatically, and in just 10 sec of cooling the needle temperature is decreased by nearly 25°C.

Figure 5 shows the needle temperature at 4000r/min of sewing with different cooling times. The optimised cooling time shows a nearly 50°C decrease in temperature with only 10sec of cooling. The needle takes almost 60 secto reach room temperature for sewing without cooling, whereas it takes just 20 secof continuous cooling to cool the needle and 30 secwith the optimised cooling time.
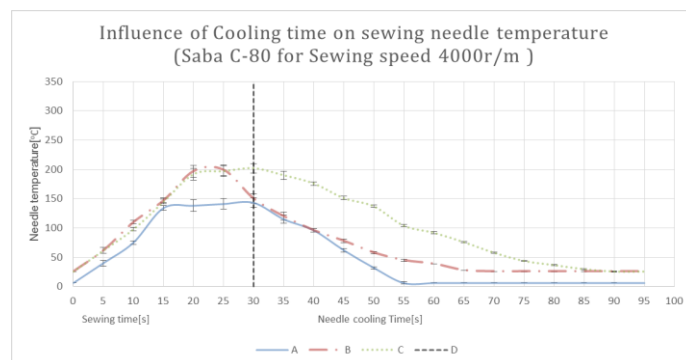

Figure 5: Influence of Cooling Time on Sewing Needle Temperature (Saba C-80) at 4000r/min

Figure 6 shows the needle temperature at 4700r/min of sewing with different cooling times. The optimised cooling time shows a nearly 90°C decrease in temperature with only 10sec of cooling. The needle takes almost 70 secto reach room temperature for sewing without cooling, whereas it takes just 30 sec by continuous cooling to cool the needle and 35 secwith the optimised cooling time.
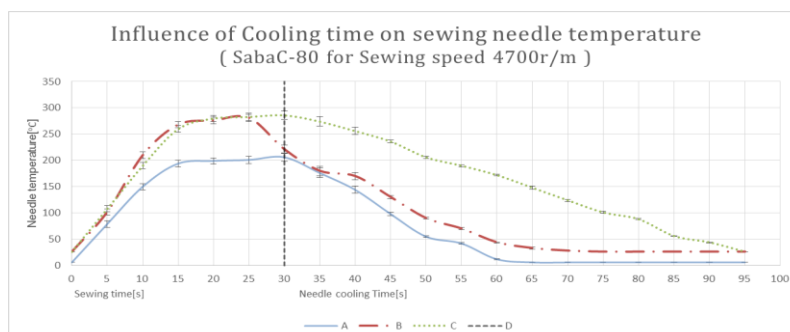

Figure 6: Influence of Cooling Time on Sewing Needle Temperature (SabaC-80) at 4700r/min

Figures 7-9 show the needle temperature for the Saba C-35 thread at different sewing speeds and with different cooling times. It was observed that higher count thread causes the needle temperature to increase, and also causes a quicker cooling time, which may be due to the contact area of the thread with the needle.

Figure 7 shows the needle temperature (Saba C-35) at 3000r/min with different cooling times. The optimised cooling time shows a nearly 60°C decrease in temperature. The needle takes almost 40sedto reach room temperature for sewing without cooling, whereas it takes just 20 secof continuous cooling to cool the needle and 25secusing the optimised cooling time.
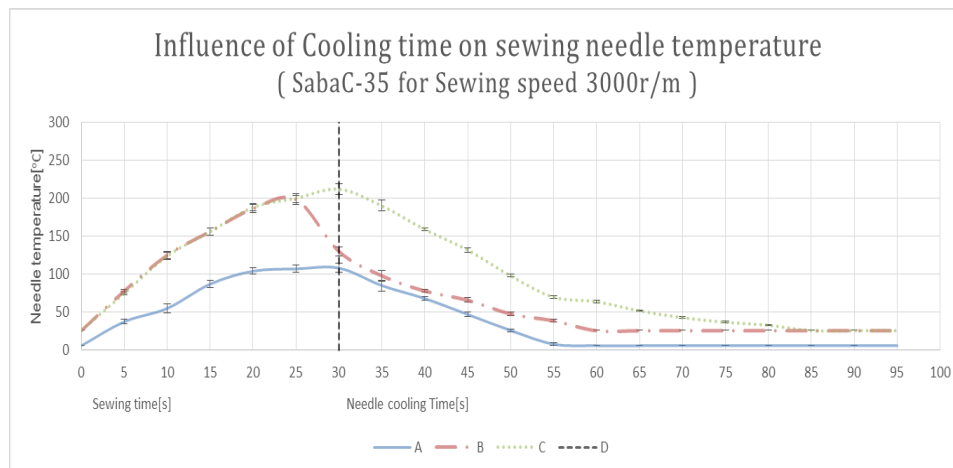

Figure 7: Influence of Cooling Time on Sewing Needle Temperature (Saba C-35) at 3000r/min

Figure 8 shows the needle temperature (Saba C-35) at 4000r/min with different cooling times. The optimised cooling time shows nearly 90°C of decrease in temperature.The needle takes almost 40 secto reach room temperature for sewing without cooling, whereas it takes just 20 sec by continuous cooling to cool the needle and 30 secwith the optimised cooling time.
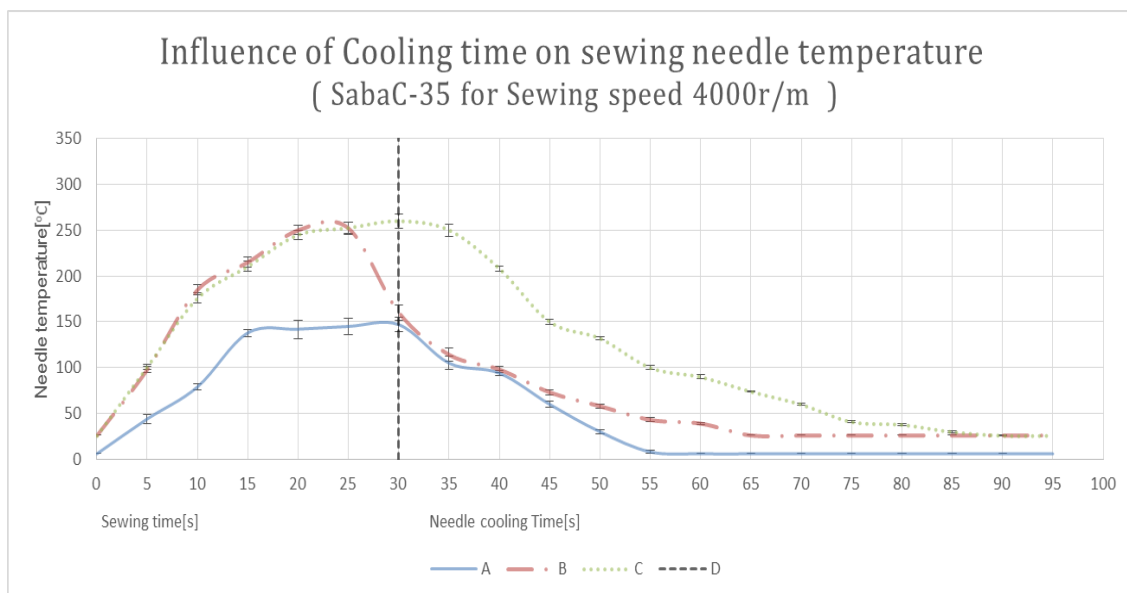

Figure 8: Influence of Cooling Time on Sewing Needle Temperature (Saba C-35) at 4000r/min

Figure 9 shows the needle temperature (Saba C-35) at 4700r/min with different cooling times. The needle temperature reaches almost 300°C after 30 sec of sewing without cooling, which is nearly 100°C higher than the needle temperature with cooling, whereas the optimised cooling time of 10 sec decreases the needle temperature by 90°C and the
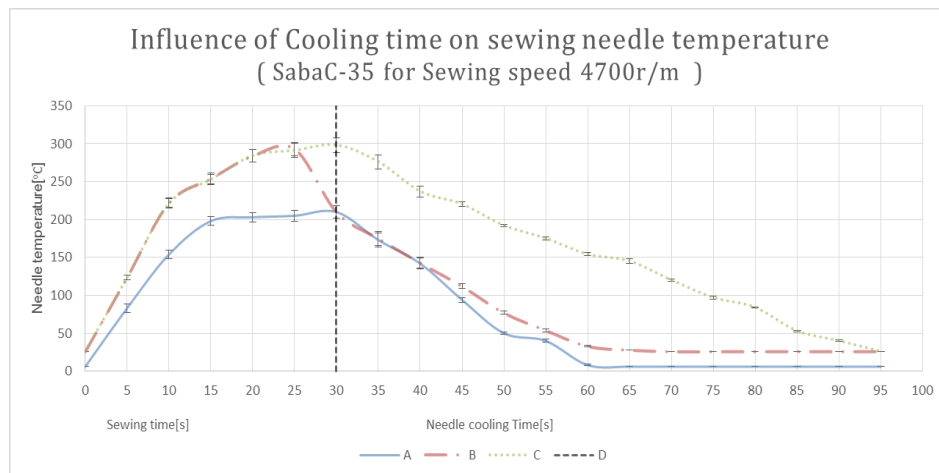
needle reaches room temperature in less than 30 sec.

Figure 9: Influence of Cooling Time on Sewing Needle Temperature (Saba C-35) at 4700r/min

Influence of Cooling Time on Tensile Properties of Thread

The needle thread is pulled out of the seam by precisely cutting the bobbin thread. Tensile properties like tenacity, initial modulus and breaking elongation of the thread were tested 20 times each to observe the effect of the cooling time on the thread strength. It was seen that sewing without cooling showed the weakest thread, where the tenacity of the thread was decreased to 26% at 4700r/min for the Saba C-80; however, the sewing with continuous cooling and partial cooling (10sec) showed almost the same tenacity of the seam thread. Figure 10 shows the tenacity of the thread for the Saba c-80 at different speeds and cooling times. The effect of the needle heat is quite visible at speeds higher than 3000r/min.

Figure 10: Tenacity of Thread (Saba C-80) at Different Speeds and Cooling Times

Figure 11 shows the tenacity of the thread (Sabac-35), with a 30% decrease in the tenacity of the seam thread at 4700r/min of the sewing machine, which is 4% higher than the Saba C-80. Sewing without cooling shows the weakest thread, where the tenacity of the thread is decreased to 30% at 4700r/min; however, sewing with continuous cooling and partial cooling (10sec) shows almost the same tenacity of the seam thread. The effect of the needle heat is quite visible for 3000r/min and higher.
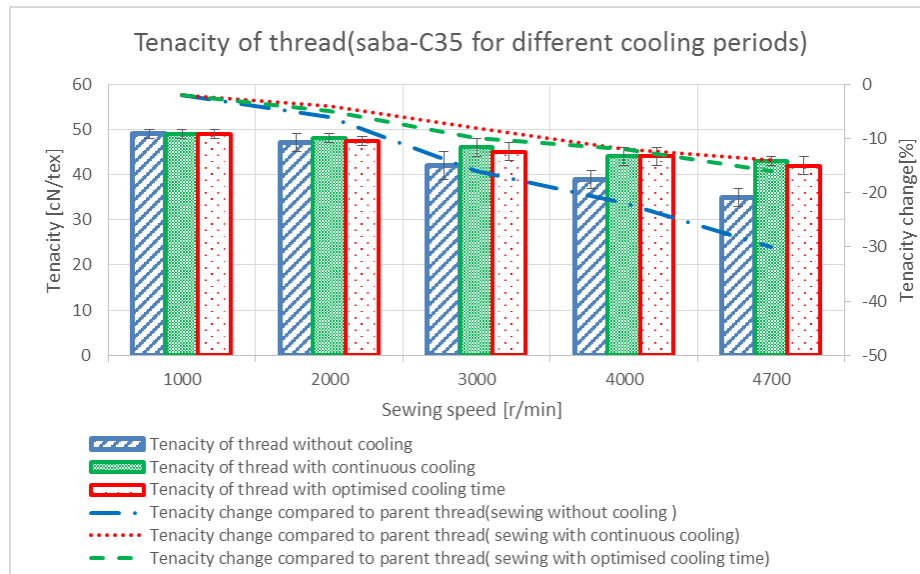
Figure 11: Tenacity of Thread (Saba c-80) at Different Speeds and Cooling Times

Table 5 shows the tensile properties of the thread, like tenacity, initial modulus and breaking elongation, of the Saba C-35 and Saba C-80 sewing thread. The percentage change in the property is also calculated according to equation 1.It shows that the thread tenacity, initial modulus and breaking elongation are more decreased for Saba C-35, when compared to Saba C-80, which is due to a higher needle temperature during the sewing process for Saba C-35.

The tensile properties of the thread are greatly decreased at 3000r/min and higher. At 4700r/min,for the Saba c-35, the initialmodulus of the thread compared to the parent threadwas 26% less for sewing without cooling, followed by 22% with the optimised cooling time and 21% using continuous cooling. For Saba C-80, the initial modulus decreases by 22% for sewing without cooling, followed by 20% with the optimised cooling time and 19% using continuous cooling.

Breaking elongation of the seam thread for 4700r/min for Saba C-35 was 21% less for sewing without cooling, followed by 16.7% with the optimised cooling time and continuous cooling. For the Saba C-80, the breaking elongation decreased by 20% for sewing without cooling, followed by 16% with an optimised cooling time and continuous cooling.

Table 5: Tensile Properties of Threads at Different Speeds of Sewing

Property			Sabac-35						Sabac-80				
			Speed of Machine						Speed of Machine				
			1000 rpm	2000 rpm	3000 rpm	4000 rpm	4700 rpm		1000 rpm	2000 rpm	3000 rpm	4000 rpm	4700 rpm
Tenacity [cN/tex]		Parent thread	50	50	50	50	50		45	45	45	45	45
	Sewing without cooling	T1	49	47	42	39	35		43	42	40	36	33
		X	-2	-6	-16	-22	-30		-4.4	-6.7	-11.1	-20.0	-26.7
	Sewing with continuous cooling	T2	49	48	46	44	43		43	42	41.2	38	37
		X	-2	-4	-8	-12	-14		-4.4	-6.7	-8.4	-15.6	-17.8
	Sewing with optimized cooling time	T3	49	47.5	45	44	42		43	42	41	37	36
		X	-2	-5	-10	-12	-16		-4.4	-6.7	-8.9	-17.8	-20.0
Breaking elongation [%]		Parent thread	18	18	18	18	18		21	21	21	21	21
	Sewing without cooling	B1	17.6	16.2	15.6	14.6	14.2		19.6	19	18.2	17.3	16.8
		X	-2.2	-10.0	-13.3	-18.9	-21.1		-6.7	-9.5	-13.3	-17.6	-20.0
	Sewing with	B2	17.7	16	16.4	15.4	15		19.7	19.2	18.8	18	17.6

	continuous cooling	X	-1.7	-11.1	-8.9	-14.4	-16.7		-6.2	-8.6	-10.5	-14.3	-16.2
	Sewing with optimized cooling time	B3	17.6	16.1	15.9	15.5	15		19.6	19.2	18.6	17.8	17.6
		X	-2.2	-10.6	-11.7	-13.9	-16.7		-6.7	-8.6	-11.4	-15.2	-16.2
Initial Modulus [N/tex]		Parent thread	4.5	4.5	4.5	4.5	4.5		3.2	3.2	3.2	3.2	3.2
	Sewing without cooling	I1	4.4	4.4	4.1	3.6	3.3		3.1	3.1	3	2.8	2.5
		X	-2.2	-2.2	-8.9	-20.0	-26.7		-3.1	-3.1	-6.3	-12.5	-21.9
	Sewing with continuous cooling	I2	4.5	4.3	4.1	4	3.6		3.1	3.1	3.1	2.7	2.6
		X	0.0	-4.4	-8.9	-11.1	-20.0		-3.1	-3.1	-3.1	-15.6	-18.8
	Sewing with optimized cooling time	I3	4.4	4.3	4.2	3.95	3.5		3.1	3.05	3	2.8	2.55
		X	-2.2	-4.4	-6.7	-12.2	-22.2		-3.1	-4.7	-6.3	-12.5	-20.3

Where:

- X=percentage change with respect to parent thread property [%]. (calculated according to Equation 1.)

- T1, T2 and T3 show the tenacity [cN/tex] of the threads without cooling, with continuous cooling and with an optimized cooling time, respectively.

- B1, B2 and B3 show the breaking elongation [%] of threads without cooling, with continuous cooling and with an optimized cooling time, respectively.

- I1, I2 and I3 show the initial modulus [N/tex] of the threads without cooling, with continuous cooling and with an optimized cooling time, respectively.

CONCLUSIONS

The following includes the major outcomes from this research.

- The sewing needle temperature influences the tensile properties of the thread, and the impact is higher for a higher thread count, which can be due to the larger contact area between the thread and the needle. Saba C-35 showed a 20°C higher temperature than the Saba C-80.At 4700r/min of sewing speeds(without cooling) Saba C-35 thread tenacity decreased by nearly 30%, followed by SabaC-80 thread, which showed a 26% decrease in tenacity.

- Air cooling (Vortex) is an effective way of decreasing needle temperature, and the continuous cooling method decreases the needle temperature by nearly 100°C at 4000r/min and 4700r/min; whereas the 10 sec cooling at the time of machine stoppage decreases the needle temperature by 92°C at 4000r/min and 4700r/min (tensile property change is shown in Table 5).

- At high speed sewing, the contact time between the thread and needle is very low, but as the machine comes to a complete stop, the contact time of the thread and needle is relatively higher, which causes damage to the sewing thread. The results represents that cooling at the time of machine stoppage and continuous coolingshow the same results in terms of thread tensile properties.

- Cooling only at the time of machine stoppage can save 60-80% on energy consumption.

- Industrial sewing machine producers must operate the air cooling device with the machine speed pedal, which operates at3000r/min and higher, and at the time of machine deceleration.

ACKNOWLEDGEMENTS

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